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RECENT ACHIEVEMENTS IN METEORITICS

-USSR-

By Academician V. G. Fesenkov

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## FOREWORD

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## RECENT ACHIEVEMENTS IN METEORITICS

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[Following is the translation of an article by Academician V.G. Fesenkov in Meteoritika (Meteoritics), Vol XVIII, Moscow, 1960, pages 5-16.]

Much attention is presently being devoted to the determination of the isotope content in various elements found in meteorites, including those isotopes which are the products of radioactive decay.

Knowledge of the isotope content is tied in directly with the possibility of determining the age of iron and stone meteorites. A detailed account of the history of attempts to determine the age of meteorites by radioactive methods will be found in the article by Geiss published in 1957 (1); those interested in the subject are advised to look up that source.

Let us take a few words to remind the reader of the crux of the problem. As is known, the uranium-lead method gives fully reliable values for the age of meteorites (about 4.5 billion years). The rubidium-strontium method, and in a number of cases the argon technique yields completely analogous results. It may be said that the "radioactive" age represents the time elapsed during the zone of hardening of the meteoric substance, which may have taken place within some considerably greater mass wherein the meteoric substance was not subject to the action of cosmic rays.

The simpler method of meteorite age determination by means of gaseous helium content measurement employed for a number of years by Panet and his associates cannot be expected to give reliable results not only due to the possibility of helium leakage into space, but mainly because part of the helium in meteorites arises through the action of

cosmic rays and is therefore of non-radiogenic origin. Thus, much of the helium found in meteorites which have been in interplanetary space for extended periods is not characteristic of radioactive decay, since part of it is formed in meteorites due to the direct interaction of cosmic rays with iron and other atomic nuclei.  $\text{He}^3$  is formed in such a reaction, but the main product is  $\text{H}^3$ , which subsequently becomes the same  $\text{He}^3$  isotope. It is perfectly obvious that knowing the tritium and  $\text{He}^3$  isotope content in a given meteorite sample and the number of tritium disintegrations per unit mass per unit time, it is possible to determine the length of time it would require for the observed amount of helium isotope to accumulate. In performing these calculations, it is necessary to assume that the meteorite had been subjected to a definite, for example (and most simply) a constant, range of cosmic ray irradiation.

The use of this method by Behemann, Geiss, and Hess (2) on two meteorite samples which had fallen in Norton County on 18 February 1948 showed that the corresponding period of time had to be 420 and 480 million years, if the entire amount of  $\text{He}^3$  could be considered as having arisen out of the tritium transformation process. Actually, a quantity of  $\text{He}^3$  is formed directly as a result of cosmic ray irradiation. Taking this into account, a somewhat smaller value, namely 240 and 280 million years, is obtained for the tritium transformation, 260 million years on the average. It is necessary to note that under the direct action of cosmic rays not only tritium nuclei, but also helium  $\text{He}^3$  and  $\text{He}^4$  nuclei are formed. The radioactive decay process, furthermore, produces only  $\text{He}^4$   $\alpha$ -particles. Knowing theoretically the ratio  $\text{He}^3/\text{He}^4$  characteristic for cosmic rays, it is possible from the observed amount of  $\text{He}^4$ , which was formerly wholly ascribed to radioactive decay, to find the portion actually produced in the disintegration of uranium and thorium nuclei. Thus it is possible to introduce corrections into the former meteoric age estimates obtained by Panet, and also, separating the radiogenic and cosmogenic components, to determine the duration of the cosmic ray irradiation of meteorites.

In his article entitled "The Origin and Age of Meteorites", Singer (3), taking the ratio of cosmogenic  $\text{He}^3$  and  $\text{He}^4$  to be 0.5 for six meteorites investigated, determined that the duration of cosmic irradiation of the meteorites totalled 300 million years -- a figure which differs little

from that obtained by the indicated method for the Norton County meteorite.

The determination of content for various isotopes affords a means not only of estimating the duration of such "radiation" age, but also of obtaining an indication of the intensity constancy of cosmic ray irradiation for the time of the meteorites' existence as individual bodies travelling in interplanetary space.

Various elements are formed in the irradiation of iron nuclei by cosmic rays; these are mostly unstable, however: tritium -- a radioactive hydrogen isotope with a half-life of 12 years becoming helium isotope  $\text{He}^3$ ,  $\text{Cl}^{36}$  and argon isotope  $\text{Ar}^{36}$ , with the first passing into the second with the loss of a single electron and with a half-life of  $4.5 \times 10^5$  years; finally,  $\text{Ar}^{40}$ ,  $\text{K}^{40}$ , and  $\text{Ca}^{40}$  are produced, with the radioactive potassium isotope passing into calcium and argon with a half-life of 1.3 billion years (4). In addition to this, radioactive isotopes  $\text{Ar}^{39}$  and  $\text{Be}^{10}$ , as well as isotopes of other elements with differing half-lives are produced in meteorites. Attempts to determine the intensity of cosmic rays in the past, as well as of meteoric age on the basis of various radioactive isotope contents were made by Martin, Fireman, Schwarzer, et al. (5). Apparently, the intensity of cosmic radiation in the past may be considered more or less constant. It is interesting to note that in individual instances, radiation ages of about a billion years and over are obtained (the Norfolk Meteorite -- 0.9 billion, and the Para de Minas Meteorite -- 1.7 billion years) (6).

Generally speaking, this radiation age differs sharply from that obtained with the aid of previous techniques (lead-uranium, rubidium-strontium, argon), and has a totally different significance. It evidently represents not the length of time elapsed since the hardening of the meteoric substance, but rather the time that these objects have existed as independent cosmic bodies of small dimensions subject to cosmic ray irradiation. The problem however, is extremely complex.

As was indicated, Singer takes the ratio of cosmogenic  $\text{He}^3$  and  $\text{He}^4$  to be approximately 0.3. This ratio is not constant, however, and must vary with time and the position of the substance being studied within the meteorite if the latter had been of sufficient mass. The change in time is caused by the constant decay of tritium, although

its low content cannot seriously affect the results. The change with position within the meteorite arises from the fact that its outer layers shield the inner mass from the impingement of primary cosmic rays. Actually, back in 1950, Le Center showed that the  $\text{He}^3/\text{He}^4$  ratio likewise falls off with decreasing excitation potentials. Consequently, small meteorites would be expected to contain a much greater relative  $\text{He}^3$  content; according to Martin (8), however, the  $\text{He}^3/\text{He}^4$  ratio in large meteorites must be sufficiently constant and equal to about 0.29 and not 0.5 as Singer supposed.

Thus, in order to render more precise the technique of determining the radiation age of meteorites, it would be highly expedient to obtain the content of various isotopes in pieces of very large meteorites, provided it is possible to establish the position of these fragments within the initial body of the meteorite. The enormous Sikhote-Alinskii meteorite, whose initial mass was no less than a thousand tons, could well serve this purpose. Although the meteorite was fragmented shortly before reaching the ground, the careful study of the morphological properties of the fragments undertaken by Ye.L. Krinov (9) does afford some notion of their position in the original mass.

The paper of A.P. Vinogradov, I.K. Zadornozhnyy, and K.F. Florenskiy (10) lists the content of helium and its isotopes in three fragments of meteorites according to 11 samples taken at various depths from the surface of the initial mass. In the authors' estimate, the greatest depth lay a distance of 100-150 cm (centimeters) from the surface. Both the total helium content and the  $\text{He}^3/\text{He}^4$  ratio were determined. These data were used by A.A. Yavnel' (11) for ascertaining the ratio of  $\text{He}^3$  to the cosmogenic helium  $\text{He}^4$  content, which for the deeper portions of the meteorite turned out to be 0.24 -- a somewhat smaller figure than the lower limit of 0.25 obtained for this ratio by Reasbeck (12). Knowing this ratio which is found to be sufficiently constant for the deep portions, where it is determined by the action of secondary cosmic rays, it is easy to derive the amount of purely radiogenic  $\text{He}^4$  helium (from the total content of helium and its isotopes). In the case of the Sikhote-Alinskii meteorite, the radiogenic  $\text{He}^4$  content was found to be  $0.10 \times 10^{-6}$  centimeters<sup>3</sup>/gram, according to the same data. As soon as the uranium content in this meteorite is determined, it will be possible to calculate its age since the time of its hardening or the final moment of heating such

that helium escape could have taken place.

The determination of the uranium content represents a very difficult problem due to the fact that it is present in very insignificant amounts. Ebert, Koenig, and Waenke describe a new technique for obtaining such a determination by measuring the content of  $\text{Xe}^{133}$  produced in  $\text{U}^{235}$  decay. The method was applied to three meteorites -- Pultusk, Breitscheid, and Acaba -- and gave results in agreement with those obtained in other ways.

F. Hernwegger and Waenke (13) employed another method of determining the uranium content in three chondrites (Acaba, Bedgeleit, and Breitscheid), by finding the content of barium produced in the neutron irradiation of  $\text{U}^{235}$ . This barium isotope,  $\text{Ba}^{140}$ , is quickly transformed into active lanthanum  $\text{La}^{140}$ , and then even more quickly -- into stable cerium  $\text{Ce}^{140}$ . If it is supposed that the concentration of thorium is thrice that of uranium, the age of the first two meteorites by the helium method is found to be 3.6 and 3.3 billion years.

E.K. Gerling and L.K. Levskiy (14) have been concerned with the inert gas content in stone meteorites and the problem of the origin of these gases. They measured the rate of neon  $\text{Ne}^{20,21,22}$  and argon  $\text{Ar}^{36,38}$  isotope accumulation in stone meteorites irradiated by cosmic rays in space. The indicated accumulation rate turned out to be about the same for meteorites of widely differing age. From this it is possible to draw the very interesting conclusion that the intensity of cosmic rays has remained constant over several billion years. This, furthermore, provides a measure of justification for the method of determining the radiation age of meteorites by their helium isotope  $\text{He}^3$  content.

According to the data of the same authors, the Staroye Pes'yanoye Meteorite (achondrite-chladnite) has a curious peculiarity: it contains an unusually high proportion of helium. This fact was first established by V.V. Cherdyntsev and later confirmed by E.K. Gerling, who also pointed out the presence of argon and neon in the meteorite in amounts exceeding those appropriate for its age. This gives rise to an interesting problem as to the origin of these gases and whether this might not hinder the formulation of the general problem of meteorite age determination by the helium method.

It may thus be assumed that the age of the meteoritic substance proper, i.e., the length of time elapsed from the moment of hardening is wholly distinct from the radiation age

during which the meteorites are subjected to the action of cosmic rays. As far as can be ascertained, this radiation age is different for various meteorites, while the time elapsed since the hardening of their substance is the same and, incidentally, differs little from the age of the solar system.

Thus, modern data on the age of meteorites testifies ever more definitely in favor of the hypothesis that the meteoritic substance must have been formed within sufficiently large asteroids during the first epoch of existence of the solar system. Subsequently, the asteroids underwent fragmentation, apparently as a result of mutual collisions.

Examining the establishment of a state of equilibrium between the metallic and silicate phases within a typical parent body in which meteoritic substance had been formed, and also basing his view on several other considerations (for example, the known fact of the transformation of graphite into diamond at high temperatures and pressures), Lovering (15) came to the conclusion that this parent body was in all probability the size of our Moon. In the epoch during which the crust of this body began to crystallize, and while the metallic core was still in a molten state, its temperature may have been approximately  $2000^{\circ}$  at a pressure of  $10^4$ - $10^5$  atmospheres. Furthermore, before the fragmentation of the body could have taken place, its core must have cooled down to  $700^{\circ}$ . Such suppositions are in many ways dubious, but they do reflect a perfectly legitimate desire to obtain an indication of final consequences of a cosmogonic character on the basis of new facts established by modern meteoritics. In the future, more reliable hypotheses on the disintegration of asteroidal bodies resulting in the creation of meteorites will require more precise methods of determining radiation age, the duration of cosmic ray irradiation. Such a disintegration must have taken place largely in the region of the asteroidal belt. The newly-formed meteoritic bodies must have finally begun to move along orbits intersecting that of the earth, for only in this way is their collision with our planet possible. It is natural to assume that the beginning of asteroidal disintegration took place in the earliest epoch of existence of the solar system. If this is the case, then the question arises as to why the radiation age in most cases constitutes a completely insignificant part of the age of the solar system. Opik and Singer have found that the radiation age of meteorites is the product of two



functions: the time-dependent probability of disintegration having a maximum in the early epoch of the existence of the solar system, and the exponential sweep factor with a mean period of 100-200 million years (16).

From calculations of the probability of meteoritic collisions with the earth, it follows that the meteorites presently being observed are the results of the final fragmentations which had taken place only several hundred million years before. This problem is a very difficult one from the theoretical standpoint and required additional experimental data. It is clear at any rate, that the formation of meteorites is accompanied by the production of great quantities of fine dust which moves out into interplanetary space and slowly settles on the Sun as a result of radiation pressure [see note]. [Note: the Poynting-Robertson effect.] Dust particles of sufficiently small size (on the order of a tenth of a micron) are swept out of the solar system by photonic pressure. As a result of all this, the solar system, largely in the plane of the ecliptic, is filled with fine meteoritic material which diffuses solar rays and appears to the terrestrial observer to have the form of a diffuse luminescence, known by the name of zodiacal light. This is confirmed by the fact that using the known distribution of asteroids according to their orbital declinations it is possible with a fair amount of precision to reproduce the observed isometric plots of zodiacal light intensity. In addition to this, all of the other properties of zodiacal light -- its apparent brightness, degree of polarization, and color -- can also be explained by the supposition regarding its origin in asteroidal dust (17). On the premise that the dust responsible for the zodiacal light phenomenon merely diffuses solar rays, but does not absorb them, it is possible to determine the density of this interstellar space dust, for example in the area from the earth to the Sun. Here will evidently be the lower limit of the actual density, and turns out to have the sufficiently small value of  $10^{-23}$  grams/centimeter<sup>3</sup>. From this it is possible to determine the probable value of the total mass of meteoric particles colliding with the earth each 24 hours. It is equal to approximately 10 tons -- a value which is considerably smaller than that given at times for the micrometeorites (about 1000 tons of micrometeorites per 24-hour period), but agrees fairly well with estimates of the total meteoric mass precipitating on the earth's surface.

Research on determining the amount and composition of the fine meteoric material falling on the earth has been going on for a long time now. Attempts are being made to determine the effects of meteoric material on the optical properties of the earth's atmosphere, but they do not seem to be wholly convincing. Thus, for example, F. Link (18) seeks to establish the presence of meteoric dust in the atmosphere by determining the optical thickness of the absorption layer during lunar eclipses. The practical aspects of this technique have yet to be sufficiently worked out. The basic difficulty lies in the large angular size of the Sun, which illuminates the layers of the earth's atmosphere for the lunar observer simultaneously at different altitudes.

C. Hoffmeister (19) attempted to determine the effect of interplanetary material on the atmosphere by the systematic changes in the polarization and lucidity of the atmosphere taking place in the morning and afternoon hours; the observations were carried out during his expedition to southwestern Africa. The degree of polarization always turned out to be significantly greater in the afternoon. His explanation for this is that the earth's atmosphere is subjected to the action of oncoming meteoric material (with a maximum at about 6 a.m.), i.e., the effect in the first half of the day is greater than during the latter half. Hoffmeister's considerations, however, are far from convincing, since the observed optical properties apply to the troposphere -- the lower portion of the atmosphere, and not to the ionosphere, where the retardation of meteoric material takes place.

Buddhue (20) made a direct attempt at collecting meteoric dust infiltrating the upper layers of the earth's atmosphere in individual meteoric streams, such as the stream of Geminides. Particles of a size on the order of ten microns and resembling iron particles of meteoric origin were deposited on plates. These results are likewise dubious.

In general, attempts to determine the direct effects of meteoric dust on tropospheric processes (cloud formation, etc.) cannot at the present time be considered successful.

More definite are the studies of meteoric material deposits on the surface of the earth or on the ocean bottom. F. Hecht and R. Patzak (21) performed a chemical analysis on microscopic spherules found in tertiary deposits on the floor of the Pacific Ocean. As a rule, the spherules consist of a metallic core encrusted by a magnetite jacket. Iron, nickel and cobalt were found in the spherules, with an iron-to-

nickel ratio of 100:15, i.e., a value common for meteorites. In the given case the cosmic origin of the examined substance (spherules) is certainly admissible.

At the same time, Villiermaux (22), having performed a completely analogous investigation, obtained unexpected results: he found a considerable content of magnetite spherules in the ground with no nickel or cobalt whatever, and consequently, not of cosmic origin. The soil samples were taken on the earth's surface, at a distance of 60 kilometers from the city of Nancy along a straight line, and (for control purposes) at a depth of several meters, i.e., in the hitherto untrammelled layers of the Vosges, where industrial wastes are absent. Villiermaux showed that the particles he found were composed of magnetite  $\text{Fe}_3\text{O}_4$  and were of various sizes, from the very smallest up to 0.5-1.0 millimeters in diameter. The particles were drawn from the test samples by means of a magnet and passed through several sieves for sorting according to fineness. Their origin is uncertain. It is interesting to note that Meunier (23) back in 1878 pointed out the presence of such magnetite particles in deep artesian wells. If, moreover, the precipitation of icy meteorites contaminated by various elemental additives and organic substances is admitted as a possibility (see Buddhue's report on the falling of a piece of ice weighing 5.44 kilograms which took place on 30 August 1955 at 4 p.m. and with a clear sky (24)), then the cosmic origin of pure magnetite might not seem such a remote supposition, although this would necessitate a reappraisal of our views as to the nature of meteoritic material.

Generally speaking, finely fragmented meteoritic material is encountered in areas of impact of crater-forming meteorites, since a large meteorite falling on the earth destroys itself as well. Studies of the famous Arizona Crater continue to reveal various properties of the meteorite responsible for it. Recently, new studies were undertaken on soil samples taken every 800 meters about the rim of the crater. These soil samples include finely fragmented particles of oxidized iron and meteoritic material. The total mass of the meteorite (about 12000 tons) and direction of its trajectory were calculated anew. However the data presented in Nininger's book (25) "Arizona's Meteoritic Crater" published in 1956 by the American Meteorite Museum show that the collected samples of meteoritic substance are heterogeneous.

As Nininger points out, of 100 small meteoritic particle samples from the Barringer crater, 95-96 were in all respects both structurally and compositionally similar to the massive samples of the same meteorite, weighing hundreds of pounds. They are therefore fragments of the same body. But 4 or 5 such small samples differ in composition -- the kamazite platelets are narrower, the tenite is more distinctly in evidence, and the time required for etching is several times shorter. This seemingly would lead to the conclusion that these particles do not have their origin in the basic mass. It is true that Moulton in his time had already concluded that the meteorite which carved out the Arizona Crater was not a single meteoritic body, but rather a dense aggregate of such bodies. According to Moulton's estimate, the diameter of this cluster during its fall on the earth constituted 400-3000 feet, with a total mass of from 50,000 to 3,000,000 tons and an impact velocity of from 7 to 15 miles per second. Moulton's suppositions seem better fitted to explain the formation of a crater 1.2 kilometers in diameter, than the hypothesis of a solid body falling on earth. Actually, if the entire mass had indeed been concentrated in a single body, then the diameter of the crater would have been 30 meters (with a supposed mass of 1,000,000 tons, according to S. Wiley), or 40 times smaller than the size of the actual crater. The formation of such a large crater must have required a detonation of enormous power, and for that reason the impact velocity could have been no less than 20 kilometers/second. In that case the resistance of the rocky soil would have equalled, according to Moulton's estimate, (see his 1929 account), about  $32 \times 10^9$  grams/centimeter -- a value sufficient to have transformed the material of the meteorite along with a considerable quantity of rock in the impact area into the gaseous state.

It is not difficult to solve the problem whether the gasification of rocks in the center of the crater had actually taken place, or whether the formation of this crater involved largely a displacement and deformation of the rock. At any rate it is easier to suppose that actually the Arizona meteorite had not been a single body, and along with this, that its fragmentation into separate fragments had taken place somewhere out in cosmic space, and not near the earth's surface as a result of terrestrial atmospheric action.

In an analogous manner, the huge Tungus meteorite, whose energy on impact was estimated by F. Whipple (26) as

having been no less than  $2 \times 10^{21}$  ergs, was likewise fragmented into extremely fine particles. Accepting the above estimate for the value of its kinetic energy, the mass of the meteorite at a velocity of 20 kilometers/second must have been no less than 1000 tons (a value which is certainly extremely conservative). It is nevertheless significant that up to the present time no remains of the meteorite have been found, save some minute iron-nickel particles discovered in soil samples taken from the impact area by L.A. Kulik, staff member of the USSR Academy of Sciences Committee on Meteorites under the direction of A.A. Yavnel' (27).

Aerial photographs taken over various countries are an aid in locating new meteoritic craters. A number of such allegedly meteoritic craters have been recently discovered in the US and Canada. S. Beals (28) has reported on a newly-found crater, supposedly of meteoritic origin, in Ontario (US) [sic: actually in Canada] ( $\varphi = 44^{\circ}27'$ ,  $\lambda = 76^{\circ}38'$ ). The crater has a diameter of 1.46 miles and is filled with paleozoic deposits. By means of samples of these deposits taken by boring in various places down to the original soil bed of the crater, the initial form of the crater, very similar to that of the Barringer Crater (Arizona), was determined. As far as it is possible to ascertain, no meteoritic material remains in and around the crater, nor is there any indication of volcanic material. Data on another possible meteoritic crater have been reported by M. Innes (29), who found a round depression 8.5 miles in diameter at Deep Bay, Saskatchewan, Canada. In this case, the main basis for a conclusion regarding the meteoritic origin of the depression consists in the lack of any traces of volcanic activity. There seem to be some signs, however, of the presence of iron and nickel.

Beals (30) draws attention to the correlation in the profiles of lunar and terrestrial craters, which consequently, in his opinion, must be of common origin. A detailed study of aerial photographs of extensive areas in Canada has revealed the existence of nine other craters and crater-like formations. Four of these Beals ascribes to volcanic activity, the rest -- to the impact of huge meteorites. In addition to the already famous Chubb crater in Eastern Canada, two other formations found very recently must be mentioned: a crater at coordinates  $\varphi = 58^{\circ}03'$  and  $\lambda = 64^{\circ}33'$  in Labrador, 160 meters in diameter, almost circular, and bearing great resemblance to lunar forms; and a 1.9-kilometer crater

apparently of very great depth at  $\phi = 46^{\circ}04'$  and  $\lambda = 78^{\circ}29'$  in Brant. According to paleontological data obtained from the latter formation, its age must be at least 400 million years, it must date back to the Cambrian period.

A new meteoritic crater has likewise been found in Australia (31). Up until that time, there were two known craters of meteoritic origin on that continent -- Henbury and Boxholl Station -- both in northern Australia. The new crater, discovered during aerial reconnaissance operations, is located in Central Australia and is virtually inaccessible. The crater, about 1.8 kilometers in diameter, lies at a distance of 128 kilometers from Mount Dorin northwest of Alice Springs. It was first visited by Hossefel, who found no meteorites lying directly on the ground. There are several smaller craters in the area of the large one. Insofar as the unstable soil in the region is subject to rapid change, it may be supposed that the crater had been formed no more than 100 years ago.

In not a single one of these cases was any trace of meteoritic material found. The main basis for considering the craters to be of meteoritic origin is their rounded form, the absence of volcanic materials, conformance to the well-known relationships derived by Baldwin between the diameter, depth and rim height for lunar craters, which, according to his view, are of meteoritic origin.

In this connection, there is a very interesting recent study by D. Alter (32) regarding the nature of the dome formations and craterlets on the Moon, carried out with the aid of photographic negatives taken at the Mount Wilson Observatory.

As far back as 1909, the famous specialist on the Moon P. Puiseux (33) in his book "Earth and Moon" pointed to two remarkable instances testifying, in his opinion, to the tectonic formation of craterlets on the Moon's surface. These examples consist of two domes found in the southern part of the Sea of Tranquillity. Puiseux considered such formations to be unstable, and therefore quite rare. On negatives obtained by means of a 60-inch reflector, Alter found a number of such shapes, especially in the region of the Crater of Copernicus. These domes sometimes lie along the same fissures as the small craters, and in some cases alternate with the latter. It is difficult not to draw the conclusion that many of the small craters were formed as a result of the sinking of such domes. Noting that many cracks and fissures are con-

nected with craters of volcanic origin, the author concludes that basically, lunar forms have their origin in tectonic phenomena.

The falling of several meteorites has been noted recently. D. Edgar (34) describes a meteor shower which fell late in February 1956 in Africa on the territory of Yudutiv. The two large objects found were chondrites weighing 3000 and 448 grams, and containing olefin and pyroxene.

An exceptionally bright bolide was observed in South Kazakhstan on 25 December 1957 flying in a northwest to southeast direction at 8 a.m. on a clear day, and apparently falling in the mountainous regions of Kirghizia (35). An expedition sent out by the Meteorite Commission of the Kazakh SSR Academy of Sciences under the general direction of M.G. Karimov, having interviewed many (over 100) eyewitnesses, established all circumstances connected with the flight, but failed to locate the meteorite.

Another extremely bright bolide, likewise observed by hundreds of persons, flew over the outskirts of Alma-Ata on 29 November 1957 at about 7 a.m.

S.I. Ryng (36) relates the history of the finding of the famous Bragin meteorite (9 fragments found between 1821 and 1952); in greater detail, the same author (37) describes the latest find of another fragment of the above-mentioned meteorite, which took place in 1952 in the Kamarinskiy rayon of Gomel'skaya oblast'.

In addition to this, a new meteorite -- the Gressak -- was found in 1954 in Belorussia; it weighs about 300 kilograms, and consists of iron (94.26%) and nickel (5%), exhibiting Neumann bands in etching and undoubtedly belonging to the hexahedrites.

I.S. Astapovich (38) has recently completed a study of the conditions surrounding the Staroye Pes'yanoye and Pervomayskiy Poselok meteoritic showers. More recent precipitations -- Kunashak and Nikol'skoye -- were investigated by I.T. Zotkin and Ye.L. Krinov (39). The most uncertain factor in such work is the apparent velocity. For this reason it would be wise to indicate not only the parabolic orbital elements (a course which is patently incorrect), but also the elements found with regard to the two following suppositions about the major axis: whether the meteorite belongs to the asteroidal belt and the correspondence of its path to the size of the earth's orbit. In addition to this, it is necessary to work out indirect methods of determining the velocity

of meteoritic flight through the atmosphere on the basis the curvature of the apparent bolide trajectory between specific altitudes. In many cases, a bright bolide will be seen by many observers over a large portion of its trajectory, but the velocity of its motion always remains uncertain. It would also be very important to determine as precisely as possible the apparent and therefore the actual sizes of bolide heads, as well as to formulate an appropriate theory to cover these objects. According to Ye.L. Krinov and I.T. Zotkin, in the case of the falling of the Kunashak meteorite, the bolide head diameter corrected to null distance to the observer, was 250 meters, many times that of the actual size of the meteorite.

Another problem which requires careful study consists in determining the actual mass lost by large meteorites in their flight through the atmosphere. In regard to ordinary meteorites, no one doubts that with existing cosmic velocities, they lose mass according to the exponential law in equal proportions, independently of their initial size (40). In this connection, it should be made a regular practice in calculating the stresses set up within meteorites during atmospheric deceleration, to compare these with determinations of hardness obtained by laboratory methods. This would be especially interesting in cases such as that of the extremely fragile Nikol'skoye meteorite which fell near Moscow in 1956.

The Committee on Meteorites of the USSR Academy of Sciences keeps a continual record of meteorite falls and bolide phenomena, enlisting for this purpose the assistance of a large corps of correspondents. Thus, for example, 49 bright bolides were registered in 1956 and 73 in 1957. This valuable work will continue, and could very well lead to very interesting results, especially if the major axes of the corresponding orbits can be determined with greater accuracy.

Special mention should be made of the publication of the first volume of a collective work devoted to the Sikhote-Aliinskiy meteorite. The first volume, which includes a large illustrated atlas of craters, contains the following papers, among others:

N.B. Divari -- "On the Apparent Trajectory of the Meteorite in the Atmosphere". The author succeeded in finally establishing the trajectory curvature; zenithal distance entry angle was  $47^{\circ}$ , and the fall angle was  $30^{\circ}$ . The linear diameter of the bolide reached 0.61 kilometers. The volume of the tail was approximately 30 kilometers<sup>3</sup>.



Ye.L. Krinov -- "On the Circumstances Surrounding the Fall of the Sikhote-Alinskiy Iron Shower". Altogether 383 separate falls -- craters and depressions of various sizes -- were noted. It is interesting to point out that the fragmentation of individual meteorites which formed the craters began with a crater diameter of 9 meters. A relationship has been established between crater diameter and depth, as well as between the size of the crater and the total quantity of meteoritic material found within it. Extending this relationship to all the craters, Ye.L. Krinov estimated the total quantity of iron material falling on the territory of the crater field to have been 70 tons.

A number of other studies on the Sikhote-Alinskiy meteorite have been completed and are being printed in the Meteoritika (Meteoritics) collections.

The paper by M.I. D'yakonova presents the results of a detailed study of the chemical composition of the Sikhote-Alinskiy meteorite, with the content of schreibersite and other constituents separately determined. It may be considered conclusively established that the iron content is 93.20%, the nickel content -- 5.94%, and the cobalt content -- 0.38%, etc. The specific weight is 7.78. The camasite, trellite, schreibersite, chromite contents, etc., were separately determined.

On the basis of a detailed mineralogical analysis of the same meteorite, and mainly on the basis of microscopic analysis, L.G. Kvasha lists the following percentages: nickel-iron (camasite, rabdite, tenite, plessite) -- 98.3%, schreibersite -- 1.40%, and trellite -- 0.30%. She also studied the structure of the camasite rods and the general octahedral structure.

The paper by V.I. Kolomenskiy and I.A. Yudin deals with the microscopic mineralogical study of the fusion crust structure in individual samples of the Sikhote-Alinskiy meteorite, and the meteoric and meteoritic dust connected with this body.

Finally, the paper by A.A. Yavnel' and S.S. Fonton presents the results of studies on the mechanical properties of the Sikhote-Alinskiy meteorite. Intermediate layers in the meteorite reduce its strength by a factor of 10 and contribute to its fragmentation in falling. Upper limit for tensile strength is reached at 4.4 kg/mm<sup>2</sup> (kilograms/millimeter<sup>2</sup>), 40.6 kg/mm<sup>2</sup> for compression strength, and 13.0 kg/mm<sup>2</sup> for bending strength.

Other notable work includes the study of the most diverse physical properties of meteorites carried out by K.N. Alekseyeva at the Geology Institute of the Ukrainian SSR Academy of Sciences (41). Of special interest is her determination of meteoritic porosity, which turned out to be 2.6 times the average porosity of ultra-primary terrestrial igneous rocks. In terrestrial minerals, the amounts of micro- and macro-porosity are almost equal, while in meteorites, the latter predominates considerably. Total porosity in meteorites fluctuates between 6.7 and 18.2%. The author concludes that meteorites were formed through the agglomeration of solid particles.

Working for the Meteorite Committee of the USSR Academy of Sciences, M.I. D'yakonova and V.Ya. Kharitonova performed chemical analyses for 14 different components of 7 stone meteorites and 6 components of 5 iron meteorites.

L.G. Evasha used A.N. Zavaritskiy's technique to construct a vector diagram of the chemical composition of achondrites showing the petrographic properties of various types of achondrites and their relation to the corresponding types of rocks in the earth's crust.

J. Winchester and A. Aten (42) studied the lead content in eight iron meteorites, including samples from the Arizona crater. The lead content turned out to vary widely, with an average of 6.7%. Insofar as can be ascertained, the lead, as well as the palladium and gold content as found exclusively in the iron phase are entirely independent of the ratio between the iron and silicate phases.

According to H. Onishi and E. Sandell (43) who studied lead distribution in meteorites and terrestrial rocks, there is no significant difference in this respect between cosmic and earth matter. Nor is there any interdependence between the lead and nickel content in meteorites, with only a very weak correlation with the gold and palladium content.

In an extensive paper covering 88 iron and 9 stone meteorites, Lovering (44) and his coauthors studied the gallium, germanium, cobalt, chromium, and copper distribution with relation to nickel content and general structure. It was confirmed that as regards gallium and germanium concentrations, all meteorites definitely fall into one of four distinct groups, and that in each of these groups the content of the indicated elements fluctuates within sufficiently narrow limits.

It is interesting to note that the pallasites are

characterized by an almost equal gallium content and almost total similarity to the gallium-germanium group 3, established for meteorites in general. Remarkable correlations were also found between the concentrations of various elements.

Not considering it necessary to list all papers relating to the determination of the content in meteorites of various rare elements and minerals, I will merely say that although most such papers are devoid of general theoretical significance, they nevertheless contain important factual material which must be taken into account in examining the problem of the formation of meteoritic substance. In any case we see that meteoritics in its modern phase of development not only bears a perfectly definite relation to cosmogony, but is also beginning to secure factual data as to the history of the solar system itself.

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